

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE
in its capacity as elected Office

Date of mailing:

22 February 2001 (22.02.01)

International application No.:

PCT/GB00/02997

Applicant's or agent's file reference:

A25776 WO

International filing date:

03 August 2000 (03.08.00)

Priority date:

17 August 1999 (17.08.99)

Applicant:

WIDDOWSON, Terence et al

1. The designated Office is hereby notified of its election made:

☒ in the demand filed with the International preliminary Examining Authority on:

18 December 2000 (18.12.00)

☐ in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was

☐ was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
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1211 Geneva 20, Switzerland

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REC'D 05 DEC 2001

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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

14

Applicant's or agent's file reference A25776 WO	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/02997	International filing date (day/month/year) 03/08/2000	Priority date (day/month/year) 17/08/1999
International Patent Classification (IPC) or national classification and IPC H04B1/707		
Applicant BRITISH TELECOMMUNICATIONS public limited company		



1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 5 sheets, including this cover sheet.

☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

 These annexes consist of a total of 5 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report.
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 18/12/2000	Date of completion of this report 03.12.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Fribert, J Telephone No. +49 89 2399 8959 

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/02997

I. Basis of the report

1. With regard to the **elements** of the international application (*Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17):*)
Description, pages:

1,2,5-11	as originally filed	
3,4,4a	with telefax of	13/08/2001

Claims, No.:

11 (part),12,13	as originally filed	
1-10,11 (part)	with telefax of	13/08/2001

Drawings, sheets:

1/14-14/14	as originally filed
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2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/02997

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-13
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-13
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-13
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/GB00/02997

Reference is made to the following document:

D1: LOTTER M P ET AL: 'A class of bandlimited complex spreading sequences with analytic properties' 1996 IEEE 4TH INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS PROCEEDINGS. TECHNICAL PROGRAM. (CAT. NO.96TH8210), MAINZ, GERMANY, pages 662-666 vol.2, 1996, New York, NY, USA, IEEE, USA ISBN: 0-7803-3567-8

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Closest prior art is D1 which is mentioned in the description on page 2.
2. Object: To provide an improved way of producing a single sideband spread spectrum signal.
3. Solution and common concept: A complex spreading signal is phase shifted in accordance with a Hilbert transform.
4. This concept is not known from any of the available prior art documents. Thus there is no hint for the person skilled in the art to modify the method of D1 in a manner arriving at a method of generating an SSB signal according to claim 1; an apparatus for transmitting an SSB signal according to claim 7; a method of decoding an SSB signal according to claim 11 or an apparatus for decoding an SSB signal according to claim 13, whereby a better correlation is achieved.
5. Claims 1 and 7 have been clarified on the basis of the enclosed drawings.

Re Item VII

Certain defects in the international application

1. Independent claims 1, 7, 11 and 13 are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the prior art (document D1) being placed in

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/GB00/02997

the preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in the characterising part (Rule 6.3(b)(ii) PCT).

2. Due to obvious errors by filing amended sheets, the present claim 11 is incomplete and the equations which apparently should have been mentioned in claim 3 and on pages 3 and 4a of the description have been omitted.

According to the present invention there is provided a method of generating a single sideband spread spectrum signal comprising the steps of:

- 5 phase-shifting a complex spreading signal in accordance with a Hilbert transform to produce a phase-shifted complex spreading signal;

upconverting the complex spreading signal and the phase-shifted complex spreading signal to a higher frequency to produce the single sideband spread spectrum signal,

10

bandlimiting one of at least the complex spreading signal or the single sideband spread spectrum signal; and

- modulating one of the complex spreading signal or the single sideband spread spectrum signal with a received signal,
- 15

wherein the order in which the steps are performed is immaterial provided that the phase shifting step is performed before the upconversion step.

- 20 In a preferred embodiment of the invention the upconverting step comprises the substeps of modulating a signal of the upconverted complex signal in accordance with the real part of the complex signal combined with the imaginary part of the phase shifted complex signal; and modulating a quadrature signal of the upconverted complex signal in accordance with the imaginary part of the complex signal combined
- 25 with the real part of the phase shifted complex signal.

Preferably the complex spreading signal is derived from a sequence defined by the equation
where

- 30 $m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length is N .

The bandlimiting step may be performed prior to the phase shifting step or the bandlimiting step may be performed after the upconversion step.

In some embodiments of the invention the modulation step is performed after the
5 upconversion step.

According to a second aspect of the invention there is provided an apparatus for transmitting a single sideband spread spectrum signal, comprising: a complex spreading signal generator (1) for generating a complex spreading signal:

10 a phase shifter (3) coupled to receive the complex spreading signal via the complex spreading signal generator and for phase-shifting the complex spreading signal in accordance with a Hilbert Transform to provide a phase-shifted complex-spreading signal;

a complex modulator (6) coupled to receive the complex spreading signal and
15 the phase-shifted complex spreading signal for upconversion thereof to produce the single sideband spread spectrum signal;

a bandlimiting filter (2; 2'; 2"; 8) for bandlimiting one of at least the complex spreading signal or the single sideband spread spectrum signal; and

a data modulator (4, 5; 9) connected to receive an input signal for modulating
20 one of the complex spreading signal or the single sideband spread spectrum with the input signal.

In some embodiments of the invention the bandlimiting filter is a low pass filter
25 connected to receive the output of the complex spreading signal generator. In other embodiments of the invention the bandlimiting filter is a band pass filter connected to receive the output of the complex modulator.

4a

In some embodiments of the invention the data modulator is coupled to receive a second signal via the complex modulator.

According to another aspect of the invention there is provided a method of decoding
5 a single sideband signal comprising the steps of phase shifting a complex spreading
signal in accordance with a Hilbert Transform; upconverting the complex spreading
signal to a higher frequency; and demodulating a received signal in accordance with
the upconverted complex spreading signal.

Preferably the complex spreading signal is derived from a sequence defined by the
10 equation
where

$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length
being N .

15

CLAIMS

1. A method of generating a single sideband spread spectrum signal comprising the steps of:

phase-shifting a complex spreading signal in accordance with a Hilbert
5 transform to produce a phase-shifted complex spreading signal;

upconverting the complex spreading signal and the phase-shifted complex
spreading signal to a higher frequency to produce the single sideband spread
spectrum signal,

bandlimiting one of at least the complex spreading signal or the single
10 sideband spread spectrum signal; and

modulating one of the complex spreading signal or the single sideband spread
spectrum signal with a received signal,

wherein the order in which the steps are performed is immaterial provided
that the phase shifting step is performed before the upconversion step.

15

2. A method according to claim 1, in which
the upconverting step comprises the substeps of

modulating a signal of the upconverted complex signal in accordance with
the real part of the complex signal combined with the imaginary part of the phase
20 shifted complex signal; and

modulating a quadrature signal of the upconverted complex signal in
accordance with the imaginary part of the complex signal combined with the real part
of the phase shifted complex signal.

3. A method according to claim 1 or claim 2, in which the complex spreading
25 signal is derived from a sequence defined by the equation
where

$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length is
 N .

30

4. A method according to any one of the preceding claims in which the
bandlimiting step is performed prior to the phase shifting step.

6. A method according to any one of claims 1 to 3 in which the bandlimiting step is performed after the upconversion step.
- 5 6. A method according to any one of the preceding claims in which the modulation step is performed after the upconversion step.
7. An apparatus for transmitting a single sideband spread spectrum signal, comprising: a complex spreading signal generator (1) for generating a complex spreading signal;
- 10 a phase shifter (3) coupled to receive the complex spreading signal via the complex spreading signal generator and for phase-shifting the complex spreading signal in accordance with a Hilbert Transform to provide a phase-shifted complex-spreading signal;
- 15 a complex modulator (6) coupled to receive the complex spreading signal and the phase-shifted complex spreading signal for upconversion thereof to produce the single sideband spread spectrum signal;
- a bandlimiting filter (2; 2', 2"; 8) for bandlimiting one of at least the complex spreading signal or the single sideband spread spectrum signal; and
- 20 a data modulator (4, 5; 9) connected to receive an input signal for modulating one of the complex spreading signal or the single sideband spread spectrum with the input signal.
8. An apparatus according to claim 7, in which the bandlimiting filter is a low pass filter connected to receive the output of the complex spreading signal generator.
- 25 9. An apparatus according to claim 7, in which the bandlimiting filter is a band pass filter connected to receive the output of the complex modulator.
- 30 10. An apparatus according to any one of claims 7 to 9, in which the data modulator is coupled to receive a second signal via the complex modulator.
11. A method of decoding a single sideband signal comprising the steps of

replaced by
Article 34

According to the present invention there is provided a method of generating a single sideband spread spectrum signal comprising the steps of bandlimiting a signal; phase shifting a complex spreading signal in accordance with a Hilbert Transform; modulating a received signal in accordance with the complex spreading signal and
5 upconverting of a complex signal to a higher frequency; wherein the order in which the steps are performed is immaterial provided that the phase shifting step is performed before the upconversion step.

In a preferred embodiment of the invention the upconverting step comprises the
10 substeps of modulating a signal of the upconverted complex signal in accordance with the real part of the complex signal combined with the imaginary part of the phase shifted complex signal; and modulating a quadrature signal of the upconverted complex signal in accordance with the imaginary part of the complex signal combined with the real part of the phase shifted complex signal.

15 Preferably the complex spreading signal is derived from a sequence defined by the equation

$$\begin{aligned} a_m &= W_N^{m^2/2 + qm} & N \text{ even} \\ &= W_N^{m(m+1)/2 + qm} & N \text{ odd} \end{aligned}$$

where

$$W_N = e^{-i2\pi r/N}$$

$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length is
20 N .

The bandlimiting step may be performed prior to the phase shifting step or the bandlimiting step may be performed after the upconversion step.

25 In some embodiments of the invention the modulation step is performed after the upconversion step.

According to a second aspect of the invention there is provided an apparatus for generating a single sideband spread spectrum signal, comprising: a complex spreading signal generator; a bandlimiting filter; a phase shifter coupled to receive a spreading signal via the complex spreading signal generator for phase shifting the spreading signal in accordance with a Hilbert Transform; a data modulator connected to receive an input signal; and a complex modulator coupled to receive a complex signal via the phase shifter for upconversion of the complex signal to a single sideband signal.

- 10 In some embodiments of the invention the bandlimiting filter is a low pass filter connected to receive the output of the complex spreading signal generator. In other embodiments of the invention the bandlimiting filter is a band pass filter connected to receive the output of the complex modulator.
- 15 In some embodiments of the invention the data modulator is coupled to receive a second signal via the complex modulator.

According to another aspect of the invention there is provided a method of decoding a single sideband signal comprising the steps of phase shifting a complex spreading signal in accordance with a Hilbert Transform; upconverting the complex spreading signal to a higher frequency; and demodulating a received signal in accordance with the upconverted complex spreading signal.

Preferably the complex spreading signal is derived from a sequence defined by the equation

$$\begin{aligned} a_m &= W_N^{m^2/2 + qm} & N \text{ even} \\ &= W_N^{m(m+1)/2 + qm} & N \text{ odd} \end{aligned}$$

25 where

$$W_N = e^{-i2\pi r/N}$$

$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length being N .

CLAIMS

1. A method of generating a single sideband spread spectrum signal comprising the steps of
- bandlimiting a signal;
- 5 phase shifting a complex spreading signal in accordance with a Hilbert Transform;
- modulating a received signal in accordance with the complex spreading signal
- and
- upconverting of a complex signal to a higher frequency;
- 10 wherein the order in which the steps are performed is immaterial provided that the phase shifting step is performed before the upconversion step.
2. A method according to claim 1, in which the upconverting step comprises the substeps of
- 15 modulating a signal of the upconverted complex signal in accordance with the real part of the complex signal combined with the imaginary part of the phase shifted complex signal; and
- modulating a quadrature signal of the upconverted complex signal in accordance with the imaginary part of the complex signal combined with the real part
- 20 of the phase shifted complex signal.
3. A method according to claim 1 or claim 2, in which the complex spreading signal is derived from a sequence defined by the equation

$$\begin{aligned}
 a_m &= W_N^{m^2/2 + qm} & N \text{ even} \\
 &= W_N^{m(m+1)/2 + qm} & N \text{ odd}
 \end{aligned}$$

where

$$W_N = e^{-i2\pi r/N}$$

25

$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length is N .

4. A method according to any one of the preceding claims in which the bandlimiting step is performed prior to the phase shifting step.
5. A method according to any one of claims 1 to 3 in which the bandlimiting step is performed after the upconversion step.
6. A method according to any one of the preceding claims in which the modulation step is performed after the upconversion step.
- 10 7. An apparatus for transmitting a single sideband spread spectrum signal, comprising:
 - a complex spreading signal generator;
 - a bandlimiting filter;
 - 15 a phase shifter coupled to receive a spreading signal via the complex spreading signal generator for phase shifting the spreading signal in accordance with a Hilbert Transform;
 - a data modulator connected to receive an input signal; and
 - a complex modulator coupled to receive a complex signal via the phase
 - 20 shifter for upconversion of the complex signal to a single sideband signal.
8. An apparatus according to claim 7, in which the bandlimiting filter is a low pass filter connected to receive the output of the complex spreading signal generator.
- 25 9. An apparatus according to claim 7, in which the bandlimiting filter is a band pass filter connected to receive the output of the complex modulator.
10. An apparatus according to any one of claims 7 to 9, in which the data modulator is coupled to receive a second signal via the complex modulator.
- 30 11. A method of decoding a single sideband signal comprising the steps of
 - phase shifting a complex spreading signal in accordance with a Hilbert Transform;

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INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference A25776 WO	FOR FURTHER ACTION see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/GB 00/ 02997	International filing date (day/month/year) 03/08/2000	(Earliest) Priority Date (day/month/year) 17/08/1999
Applicant BRITISH TELECOMMUNICATIONS public limited company		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

- a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

- b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. ☐ **Certain claims were found unsearchable** (See Box I).

3. ☐ **Unity of invention is lacking** (see Box II).

4. With regard to the **title**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No.

☒ as suggested by the applicant.

☐ because the applicant failed to suggest a figure.

☐ because this figure better characterizes the invention.

3a

☐ None of the figures.

(19) World Intellectual Property Organization
International Bureau



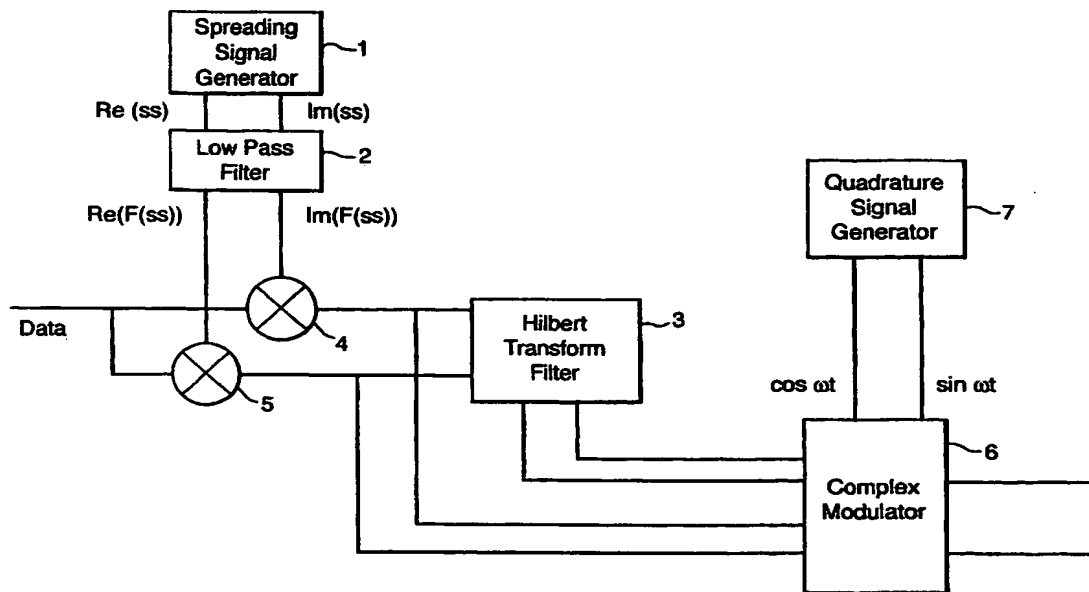
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99306490.6 17 August 1999 (17.08.1999) EP
- (71) Applicant (for all designated States except US): **BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY** [GB/GB]; 81 Newgate Street, London EC1A 7AJ (GB).
- (72) Inventors; and
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- (74) Agent: **SEMOS, Robert, Ernest, Vickers**; BT Group Legal Services, Intellectual Property Dept., Holborn Centre, 8th floor, 120 Holborn, London EC1N 2TE (GB).
- (81) Designated States (*national*): AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
- Published:
— With international search report.
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: SIGNAL GENERATOR AND DECODER



(57) Abstract: This invention relates to a signal generator and decoder for a single sideband spread spectrum signal. The present invention provides a single sideband spread spectrum signal generator and decoder in which single sideband modulation using a complex spreading code is achieved with improved correlation properties, so that the interference between users is reduced.

Signal Generator and Decoder

This invention relates to a signal generator for providing a single sideband (SSB) spread spectrum signal.

5

Currently all cellular networks use double sideband modulation to upconvert a baseband signal to a radio frequency. Hence, the same information is conveyed in both sidebands, and the signal uses twice the bandwidth than is absolutely necessary. Single sideband modulation allows the same amount of information to be
10 transmitted using half the bandwidth of double sideband modulation, or alternatively twice the amount of information in the same bandwidth.

The next generation of cellular networks is known as Universal Mobile Telecommunications Systems (UMTS). Wideband code division multiple access (W-
15 CDMA) will be used for 60MHz of paired spectrum, i.e. two separate bands of 60MHz, the lower band being used for the uplink and the higher band being used for the downlink. The use of W-CDMA facilitates high bit rates for mobile users.

The capacity of a code division multiple access (CDMA) system is determined by the
20 number of chips per symbol (known as the processing gain) divided by the energy per bit divided by noise power spectral density (E_b/N_0). If the number of chips per symbol can be increased then the capacity is increased. The maximum chipping rate is limited by the available bandwidth. Single sideband modulation reduces the bandwidth required by a modulated signal by a half. Therefore if a single sideband
25 modulated signal can be produced then either the chipping rate can be increased, or two single sideband signals (upper and lower sideband) may be employed in order to increase the capacity of a CDMA system.

However, traditional techniques used to produce a single sideband signal, such as
30 bandpass filtering or the well known phasing method cannot be used with data where the spectrum extends down to DC.

A known method of producing a single sideband signal is shown in Figure 1. However this complex modulator may not be used with traditional spreading codes such as PN code, Walsh codes, Gold code etc. to produce SSB because these codes are binary and do not provide a suitable complex spread spectrum signal. The autocorrelation and cross correlation properties of these signals are good. However, if the signal is transformed (eg. by the Hilbert transform) to produce a quadrature signal, then discontinuities and poor correlation properties result. Poor correlation properties result in an increase in the interference experienced by other users and thus decrease the capacity of the system. Hence, to use a modulator such as that shown in Figure 1 a spreading code is required which has good correlation properties in both the real and imaginary domains if a corresponding increase in capacity is to be achieved.

Complex spreading codes with the desired properties are known, for example Frank-Zadoff-Chu (FZC) codes as described in "Polyphase codes with good non-periodic correlation properties", R. L. Frank, IEEE Transactions of Information Theory, vol. IT-9, pp. 43-45, Jan. 1963. However, use of these codes produces a spread spectrum signal which is not bandlimited as will be shown later, so that whatever modulation is used the resulting signal would occupy limitless bandwidth. In "A class of bandlimited complex spreading sequences with analytic properties", M. P. Lotter and L. P. Linde, Proc of ISSSTA 95, 22-25 Sept. 1996, it was shown that by limiting the phase shift between successive samples of the sequence to be less than π radians, a bandlimited signal may be obtained and a set of codes called analytic bandlimited complex sequences derived. The penalty paid for this filtering process is that both the autocorrelation and crosscorrelation functions of the codes are no longer ideal so the number of users which may be supported is reduced. So, although the number of chips per symbol is increased in this known system, the resulting poor correlation properties do not result in a corresponding increase in capacity.

The present invention seeks to alleviate these problems by providing a single sideband spread spectrum signal generator in which single sideband modulation using a complex spreading code is achieved with improved correlation properties, so that the interference between users is reduced.

According to the present invention there is provided a method of generating a single sideband spread spectrum signal comprising the steps of bandlimiting a signal; phase shifting a complex spreading signal in accordance with a Hilbert Transform; modulating a received signal in accordance with the complex spreading signal and
 5 upconverting of a complex signal to a higher frequency; wherein the order in which the steps are performed is immaterial provided that the phase shifting step is performed before the upconversion step.

In a preferred embodiment of the invention the upconverting step comprises the
 10 substeps of modulating a signal of the upconverted complex signal in accordance with the real part of the complex signal combined with the imaginary part of the phase shifted complex signal; and modulating a quadrature signal of the upconverted complex signal in accordance with the imaginary part of the complex signal combined with the real part of the phase shifted complex signal.

15 Preferably the complex spreading signal is derived from a sequence defined by the equation

$$\begin{aligned} a_m &= W_N^{m^2/2 + qm} & N \text{ even} \\ &= W_N^{m(m+1)/2 + qm} & N \text{ odd} \end{aligned}$$

where

$$W_N = e^{-i2\pi r/N}$$

$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length is
 20 N .

The bandlimiting step may be performed prior to the phase shifting step or the bandlimiting step may be performed after the upconversion step.

25 In some embodiments of the invention the modulation step is performed after the upconversion step.

According to a second aspect of the invention there is provided an apparatus for generating a single sideband spread spectrum signal, comprising: a complex spreading signal generator; a bandlimiting filter; a phase shifter coupled to receive a spreading signal via the complex spreading signal generator for phase shifting the spreading signal in accordance with a Hilbert Transform; a data modulator connected to receive an input signal; and a complex modulator coupled to receive a complex signal via the phase shifter for upconversion of the complex signal to a single sideband signal.

- 5 In some embodiments of the invention the bandlimiting filter is a low pass filter connected to receive the output of the complex spreading signal generator. In other embodiments of the invention the bandlimiting filter is a band pass filter connected to receive the output of the complex modulator.
- 10 In some embodiments of the invention the data modulator is coupled to receive a second signal via the complex modulator.

According to another aspect of the invention there is provided a method of decoding a single sideband signal comprising the steps of phase shifting a complex spreading signal in accordance with a Hilbert Transform; upconverting the complex spreading signal to a higher frequency; and demodulating a received signal in accordance with the upconverted complex spreading signal.

Preferably the complex spreading signal is derived from a sequence defined by the equation

$$\begin{aligned} a_m &= W_N^{m^2/2 + qm} & N \text{ even} \\ &= W_N^{m(m+1)/2 + qm} & N \text{ odd} \end{aligned}$$

25 where

$$W_N = e^{-i2\pi r/N}$$

$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length being N .

According to another aspect of the invention there is provided an apparatus for decoding a transmitted signal, comprising: a complex spreading signal generator; a phase shifter connected to receive the complex spreading signal from the complex spreading signal generator; a complex modulator connected to receive the complex spreading signal from the complex spreading signal generator, connected to receive the phase shifted complex spreading signal from the phase shifter and arranged in operation to upconvert the complex spreading signal; and a data modulator connected to receive the transmitted signal and the upconverted complex spreading signal and arranged in operation to demodulate the transmitted signal to provide a decoded transmitted signal.

Methods of and apparatus for generating and decoding signals according to the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a known modulator for producing a single sideband transmission signal from an arbitrary information source;

Figure 2 shows a known complex modulator for producing a single sideband transmission signal from complex input data.

Figures 3a to 3e show embodiments of a signal generator according to the invention; Figure 4 shows ideal autocorrelation and cross correlation functions for a spreading signal of length 49 chips;

Figure 5 shows complex spreading signals for use in a signal generator according to the invention;

Figure 6 shows schematically how a signal generator according to the invention may be employed in different ways to increase capacity in a system;

Figure 7 is a graph showing bit error rate (BER) against the number of users for a system using a signal generator according to the invention, BER for a standard UMTS system using double sideband modulation and BER for a system employing a combination of the techniques which would represent the evolutionary route in the adoption of the invention where SSB and DSB systems co-exist in the same spectrum;

Figure 8 illustrates how a higher chipping rate can reduce fading (destructive interference) due to multipath propagation;

Figure 9 shows how BER varies with the time delay between a line of sight signal and an equal magnitude signal of random phase, representing the same signal received via
5 a different path;

Figure 10 shows results taken from channel sounding measurements in a typical microcellular environment demonstrating the small inter-arrival delays between multipaths in a dense urban environment; and

Figure 11 shows a decoder for decoding a signal transmitted according to the
10 invention.

Figure 1 shows a known modulator for producing a SSB. A data signal I and its corresponding quadrature signal Q are modulated at modulators 10 and 13 by a cosine wave of the modulation frequency. The data signals I and Q are also
15 modulated at modulators 12 and 11 by a sine wave of the modulation frequency. The outputs of the modulators 10 and 11 are fed to an adder 14 providing an SSB signal 16 and the outputs of the modulators 12 and 13 are fed to an adder 15 to provide an SSB output signal 17. The output at 16 is 90 degrees out of phase with the output at 17. The modulator of Figure 1 provides an upper sideband signal, a lower sideband
20 signal may be produced by changing the sign of one of the inputs to the adders 14 and 15. It will be appreciated that a modulator which simply produces one or the other of the output signals 16 or 17 could equally well be used.

Figure 2 shows a complex modulator for producing a SSB signal from a complex
25 input signal. Complex signal B is the quadrature counterpart of complex signal A. The imaginary part of complex signal B is subtracted from the real part of complex signal A (via an inverter, not shown) at an adder 20, and the resultant summed signal is then modulated by a cosine wave of the modulation frequency at a modulator 23. Similarly, the imaginary part of complex signal A is added to the real part of complex
30 signal B at an adder 21, and the summed signal is then modulated by a sine wave of the modulation frequency at modulator 22. The two modulated signals are summed at an adder 24 to produce an SSB signal. The complex modulator of Figure 2

produces an upper sideband signal, a lower sideband signal may be produced by changing the sign of one of the inputs to the adders 20 and 21.

Figure 3a shows a first embodiment of an SSB spread spectrum signal generator according to the invention comprising a complex spreading signal generator 1 which generates a complex spreading signal, denoted $\text{Re}(ss)$ and $\text{Im}(ss)$. The nature of the complex spreading signal will be described later with reference to Figure 5. The complex spreading signal is received by a low pass filter 2 which outputs a filtered complex spreading signal, the real part of which is denoted $\text{Re}(F(ss))$ and the imaginary part of which is denoted $\text{Im}(F(ss))$. The filter 2 is implemented as a root raised cosine filter, although any type of low pass filter could be used. A data signal modulates the real and imaginary complex spreading signals at modulators 4 and 5 to produce a modulated complex signal. The modulated complex signal is then phase shifted by 90 degrees using a Hilbert Transform filter 3 to produce the quadrature counterpart of the complex signal. These complex signals are then upconverted to the desired frequency by a complex modulator 6 to provide as an output an SSB spread signal. Cosine and sine waves of the desired frequency are provided by a signal generator 7.

Figure 3b shows an embodiment of the invention in which the complex signal is filtered after modulation by the input data. Equally filtering can be performed after the Hilbert transform, as shown in the embodiment of Figure 3c. This embodiment requires the use of two low pass filters 2' and 2''. Figure 3d shows an embodiment of the invention in which the upconverted SSB signal is bandlimited by a band pass filter 8.

Figure 3e shows an embodiment of the invention in which the data modulates the upconverted SSB signal at a modulator 9. It will be appreciated that bandlimiting of the signal can be performed in several ways in a similar manner to the embodiments shown in Figures 3b, 3c and 3d.

For spread spectrum communications a set of spreading signals is required each of which has an autocorrelation function which is near zero everywhere except

at a single maximum per period, and which also has minimum cross correlation functions. It has been shown by D. V. Sarwate in "Bounds on crosscorrelation and autocorrelation of sequences", IEEE Transactions on Information Theory, vol IT-25, pp720-724, that the maximum magnitude of the periodic cross correlation function
 5 and the maximum magnitude of the periodic autocorrelation are related, and that if a set of signals has good autocorrelation properties then the cross correlation properties are not very good, and vice versa. Figures 4a and 4b show perfect autocorrelation and ideal cross correlation functions (for a spreading signal of length 49 chips)

10

The complex spreading signal generator 1 generates one of a family of complex spreading signals which have good correlation properties. The codes used in this embodiment of the invention are known as Frank-Zadoff-Chu (FZC) sequences or codes. They are based on the complex roots of unity:

$$W_N = e^{-i2\pi r / N}$$

15

Where $i = \sqrt{-1}$, N denotes the FZC sequence length and r is an integer relatively prime to N. The FZC sequences are then defined as:

$$\begin{aligned} a_m &= W_N^{m^2/2 + qm} & N \text{ even} \\ &= W_N^{m(m+1)/2 + qm} & N \text{ odd} \end{aligned}$$

20 where $m = 0, 1, 2, \dots, N-1$ and q is any integer and the number of sequences of a given length is N.

The maximum instantaneous frequency reached by the sequence $\{a_m\}$ is when $m = N-1$, and can be written as:

$$\omega_{a\max} = 2\pi r \left(1 - \frac{1}{2N}\right)$$

$$\omega_{a\max} \approx 2\pi r$$

for large N

Clearly the maximum instantaneous frequency is not bandlimited to the Nyquist value for the chipping rate and depends upon r . The real and imaginary parts of an FZC
5 sequence are shown in Figure 5a. The sequence generated by the complex spreading sequence generator 1 is phase shifted by the Hilbert Transform filter 3 to produce a signal which has been phase shifted by 90 degrees. The phase shifted sequence corresponding to the complex sequence of Figure 5a is shown in Figure 5b. The complex spreading sequence and the transformed sequence each have good
10 autocorrelation and good cross correlation properties.

The operations of bandlimiting, applying the Hilbert transform, and upconversion to a broadcast frequency using a complex modulator may be performed in any order, as long as the Hilbert Transform is applied before the upconversion step. Hence, in
15 alternative embodiments of the invention the order in which the signals are filtered, spread and modulated is different. For example, referring again to Figure 3, the complex spreading signal from the spreading signal generator 1 may be phase shifted by the Hilbert transform filter 3 and then the complex spreading signal and the phase shifted spreading signal may each be filtered, although in this case two low pass
20 filters would be required. Figure 3e shows another alternative embodiment of the invention in which the data is used to modulate the upconverted spread spectrum signal.

The capacity of the system is potentially increased because either two SSB signals
25 may be used in a single existing UMTS channel or one SSB channel of twice the chipping rate may be employed, as shown schematically in Figure 6. For a practical system which allows a smooth transition from a standard using double sideband modulation to a standard using SSB modulation, it is desirable that a signal employing SSB modulation and a signal employing double sideband modulation should cause
30 minimal interference to each other. Figure 7 shows the results of an experiment to measure the BER against the number of users for a system using SSB modulation according to the preferred embodiment of the invention, the BER for a standard

UMTS system using double sideband modulation and the BER for a system employing a combination of the techniques, referred to as an 'overlay' in Figure 7.

An advantage of using an SSB channel of twice the chipping rate is that multipath resolution is improved. Multipath resolution is required when a signal may take a plurality of paths between a transmitter and a receiver. If the multipath resolution is improved, the potential increase in capacity is more than 100%, due to reduced fading and hence decreased interference. Figure 8 illustrates how a higher chipping rate can reduce interference, if it is possible to resolve signals received via different paths. It is also possible to constructively combine signals received via different paths so that the performance of a line with multipaths may actually be improved over that of a perfect channel.

Figure 9 shows how BER varies with the time delay between a line of sight signal and an equal magnitude signal of random phase, representing the same signal received via a different path. In this example the chipping rate is 4 Mchip/s with a period of 0.25 s and the E_b/N_0 is 6.8dB resulting in a BER of 1×10^{-3} when no multipath interference occurs. In this example the sampling point is midway through the chip resulting in the start of the next chip occurring after a delay 0.125 s. It can be seen that the low BER is maintained until the two signals are spaced by less than the chipping period then significant fading (destructive interference) results and the BER increases significantly.

Figure 10 shows results taken from channel sounding measurements in a typical microcellular environment. A significant multipath is defined as paths which have a signal strength within 10 dB of the strongest signal. In the graph of Figure 10 the profile width is plotted against the number of significant multipaths. It can be seen that, in many cases, all of the energy is distributed within a 0.5 s window, even when many paths are contributing. If the chipping period is 0.25 s many separate multipaths will arrive within each chip interval resulting in fading and thus degradation of system performance. Therefore, for much of the time the system is only able to resolve 2 multipaths. Increasing the chip rate not only reduces fading

but also yields more resolvable multipaths which could beneficially be combined at the receiver.

Figure 11 shows a decoder for decoding the transmitted signal of this invention. A
5 despread signal is generated using a spreading signal generator 1', a Hilbert transform filter 3', a quadrature signal generator 7' and a complex modulator 6' in a similar manner to the generation of the spreading signal shown in Figure 3e. The transmitted data is demodulated, and despread by a modulator 9, and then low pass filtered by a low pass filter 10 to achieve the decoded signal.

CLAIMS

1. A method of generating a single sideband spread spectrum signal comprising the steps of
 - bandlimiting a signal;
 - 5 phase shifting a complex spreading signal in accordance with a Hilbert Transform;
 - modulating a received signal in accordance with the complex spreading signal and
 - upconverting of a complex signal to a higher frequency;
- 10 wherein the order in which the steps are performed is immaterial provided that the phase shifting step is performed before the upconversion step.
2. A method according to claim 1, in which the upconverting step comprises the substeps of
 - 15 modulating a signal of the upconverted complex signal in accordance with the real part of the complex signal combined with the imaginary part of the phase shifted complex signal; and
 - modulating a quadrature signal of the upconverted complex signal in accordance with the imaginary part of the complex signal combined with the real part
 - 20 of the phase shifted complex signal.
3. A method according to claim 1 or claim 2, in which the complex spreading signal is derived from a sequence defined by the equation

$$\begin{aligned}
 a_m &= W_N^{m^2/2 + qm} & N \text{ even} \\
 &= W_N^{m(m+1)/2 + qm} & N \text{ odd}
 \end{aligned}$$

where

$$W_N = e^{-i2\pi r/N}$$

25

$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length is N .

4. A method according to any one of the preceding claims in which the bandlimiting step is performed prior to the phase shifting step.

5 5. A method according to any one of claims 1 to 3 in which the bandlimiting step is performed after the upconversion step.

6. A method according to any one of the preceding claims in which the modulation step is performed after the upconversion step.

10

7. An apparatus for transmitting a single sideband spread spectrum signal, comprising:

a complex spreading signal generator;

a bandlimiting filter;

15 a phase shifter coupled to receive a spreading signal via the complex spreading signal generator for phase shifting the spreading signal in accordance with a Hilbert Transform;

a data modulator connected to receive an input signal; and

20 a complex modulator coupled to receive a complex signal via the phase shifter for upconversion of the complex signal to a single sideband signal.

8. An apparatus according to claim 7, in which the bandlimiting filter is a low pass filter connected to receive the output of the complex spreading signal generator.

25 9. An apparatus according to claim 7, in which the bandlimiting filter is a band pass filter connected to receive the output of the complex modulator.

10. An apparatus according to any one of claims 7 to 9, in which the data modulator is coupled to receive a second signal via the complex modulator.

30

11. A method of decoding a single sideband signal comprising the steps of phase shifting a complex spreading signal in accordance with a Hilbert Transform;

upconverting the complex spreading signal to a higher frequency; and
demodulating a received signal in accordance with the upconverted complex spreading signal.

12. A method according to claim 11, in which the complex spreading signal is
5 derived from a sequence defined by the equation

$$\begin{aligned} a_m &= W_N^{m^2/2 + qm} & N \text{ even} \\ &= W_N^{m(m+1)/2 + qm} & N \text{ odd} \end{aligned}$$

where

$$W_N = e^{-i2\pi r/N}$$

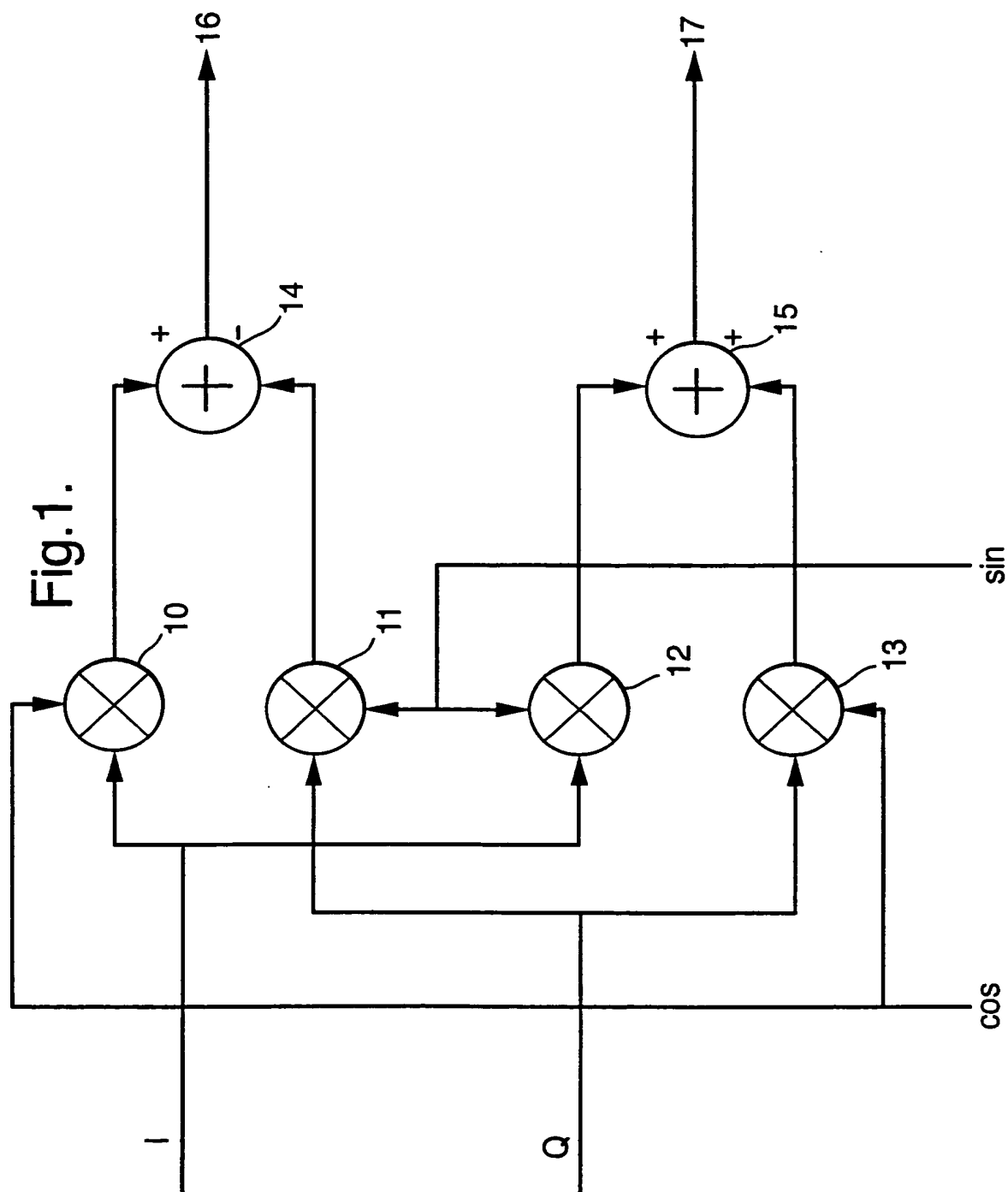
$m = 0, 1, 2, \dots, N-1$, q is any integer and the number of sequences of a given length being N .

10

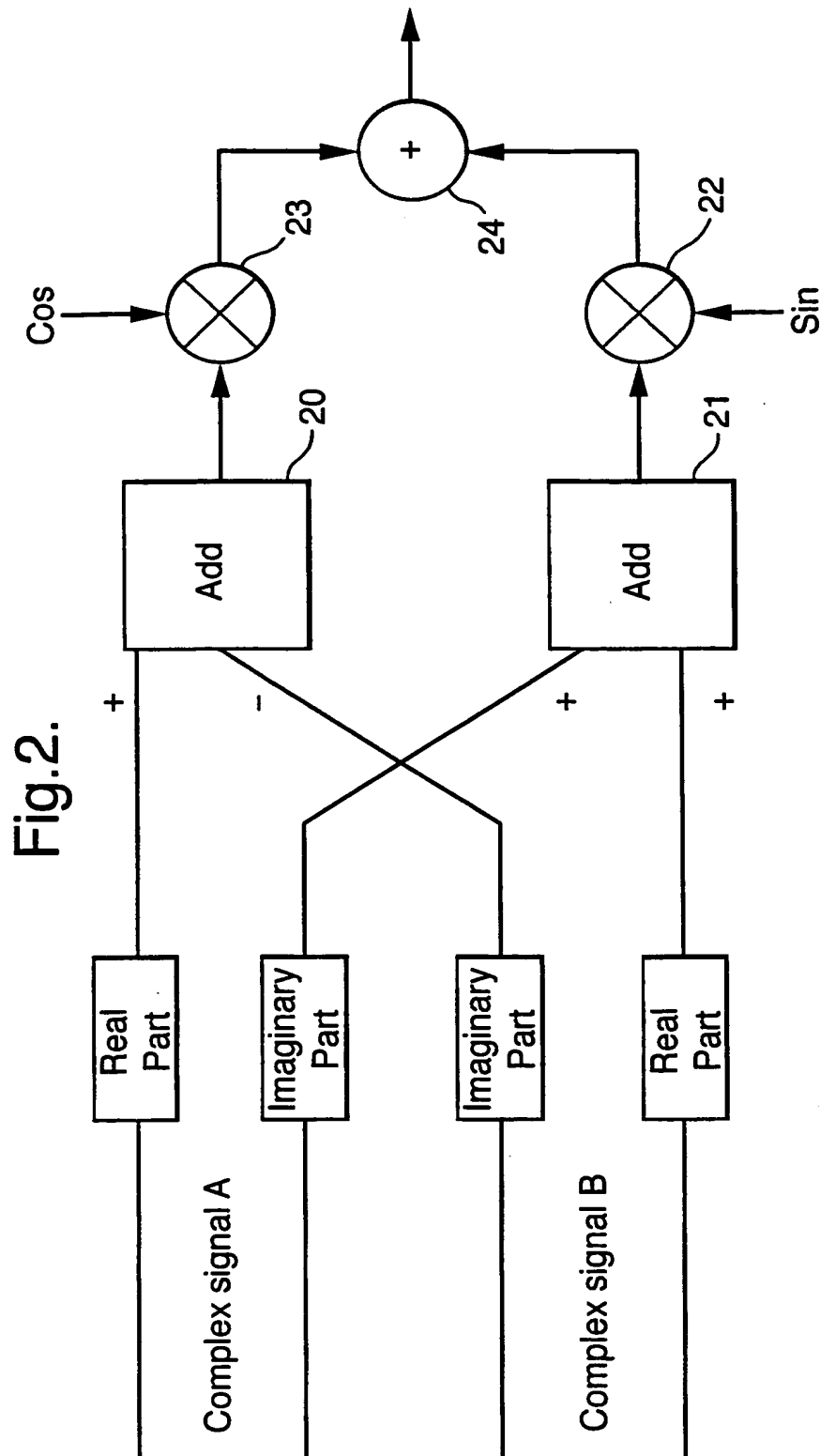
13. An apparatus for decoding a transmitted signal, comprising:
a complex spreading signal generator;
a phase shifter connected to receive the complex spreading signal from the complex spreading signal generator;

- 15 a complex modulator connected to receive the complex spreading signal from the complex spreading signal generator, connected to receive the phase shifted complex spreading signal from the phase shifter and arranged in operation to upconvert the complex spreading signal; and

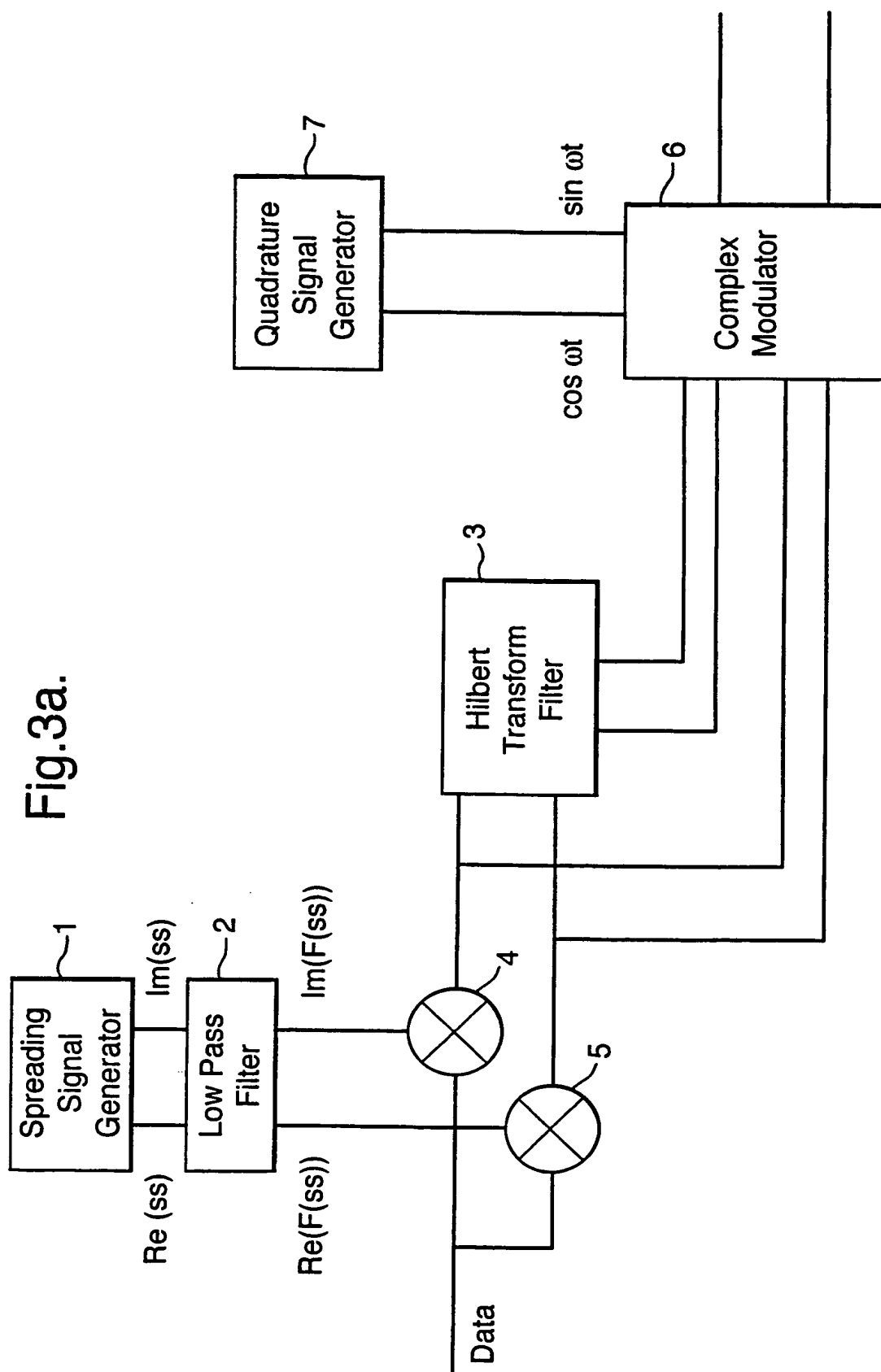
- a data modulator connected to receive the transmitted signal and the
20 upconverted complex spreading signal and arranged in operation to demodulate the transmitted signal to provide a decoded transmitted signal.



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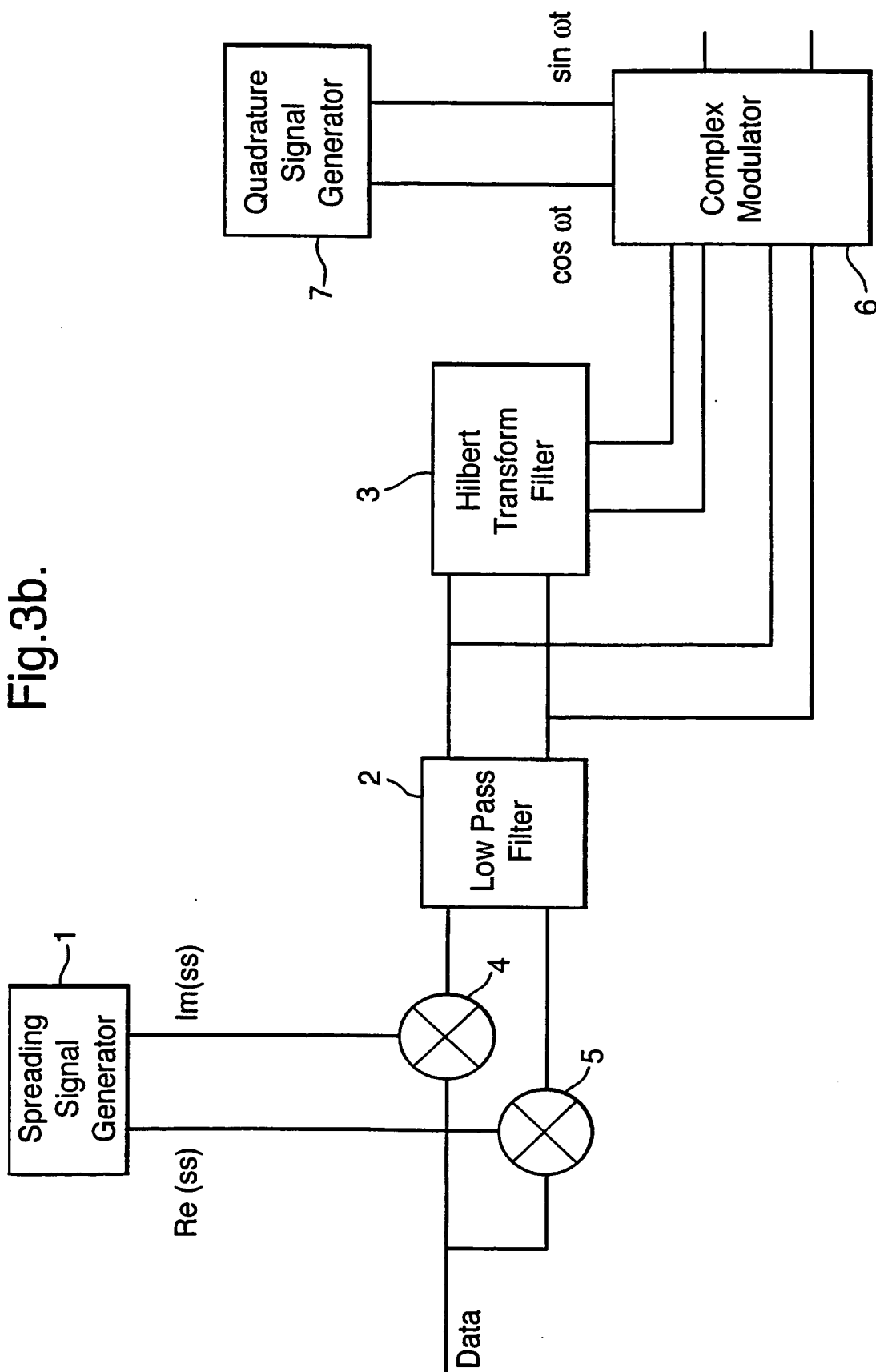


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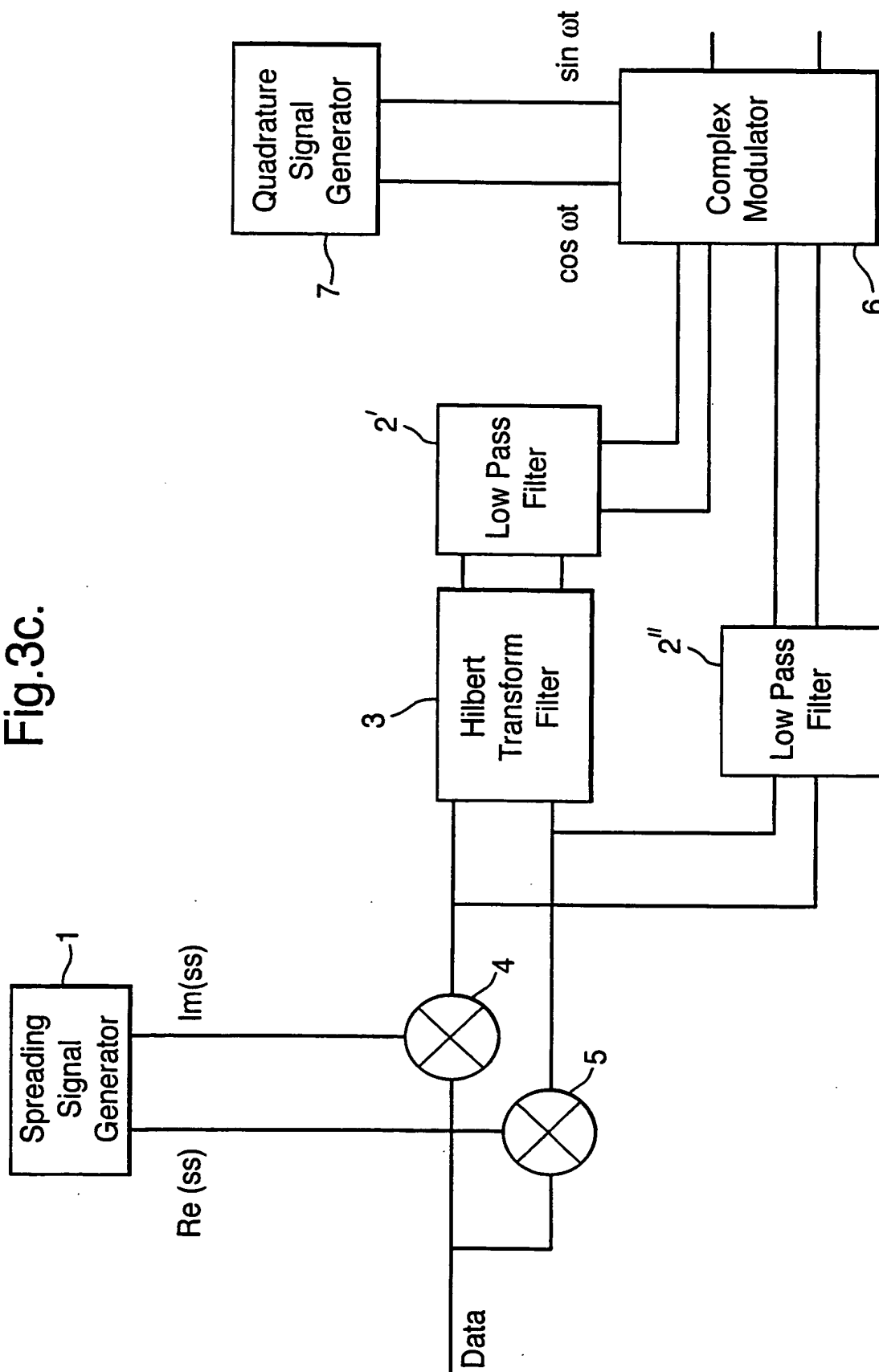
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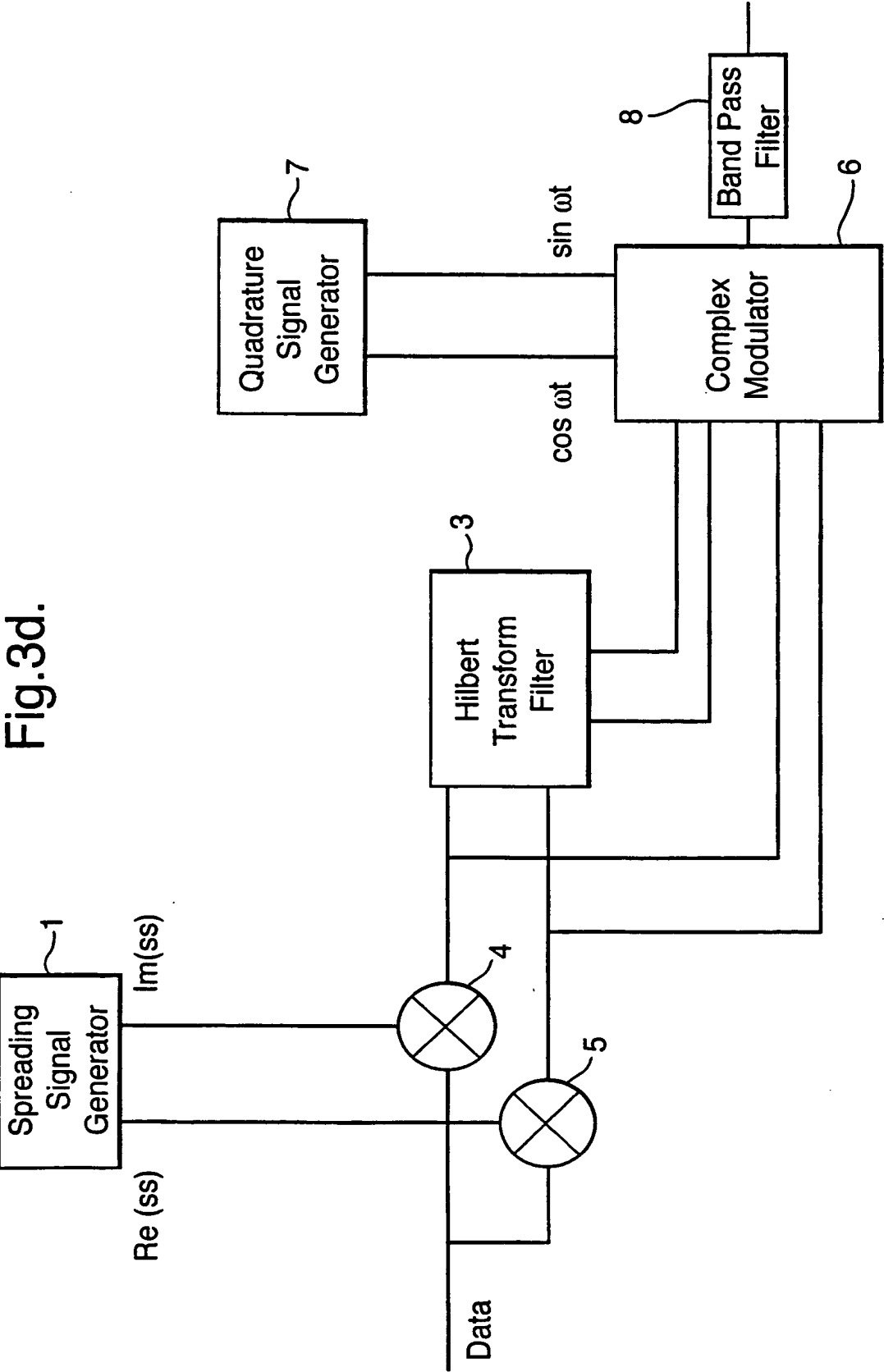
Fig.3b.

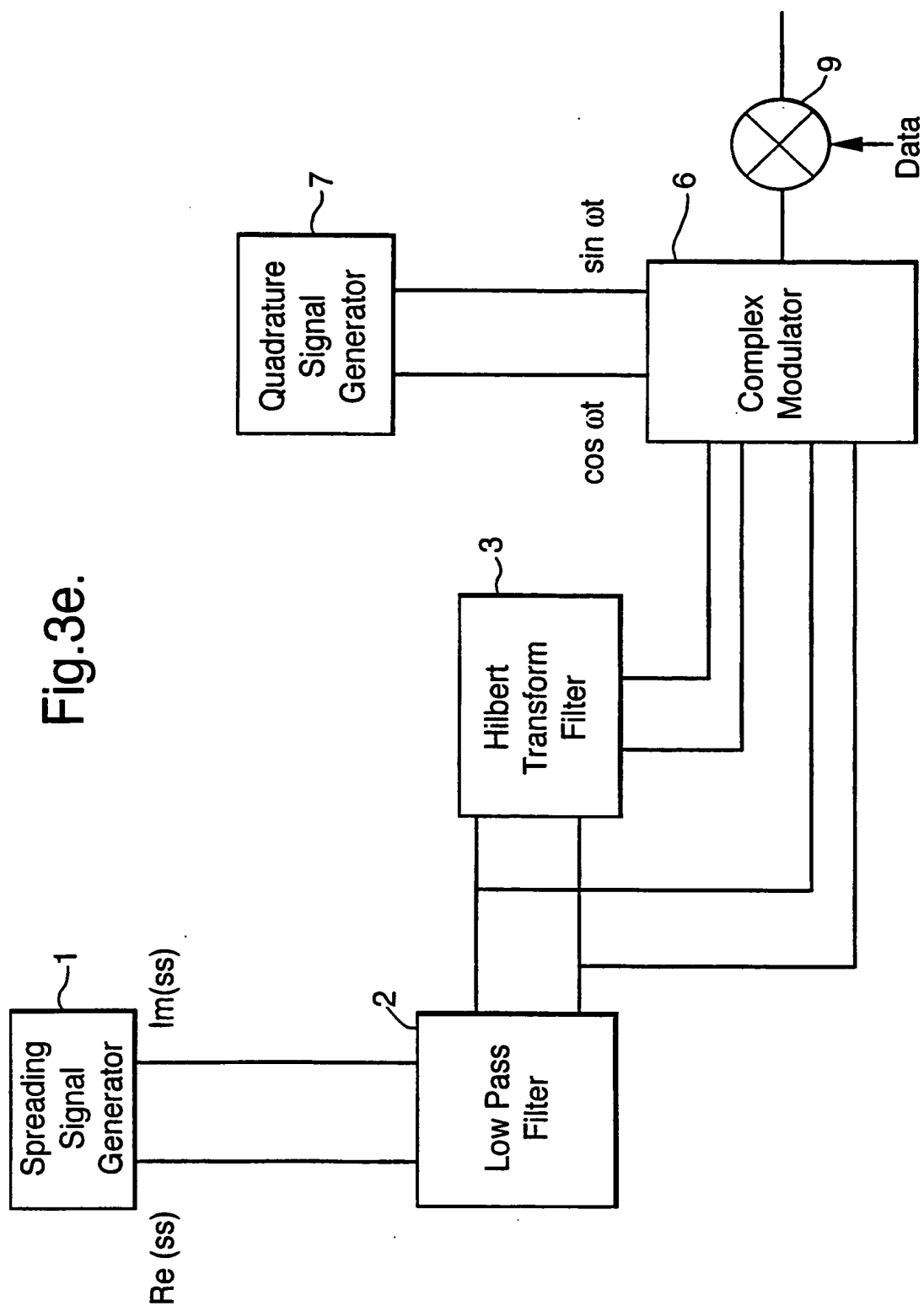


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Fig.3c.







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Fig.4a.

Autocorrelation function

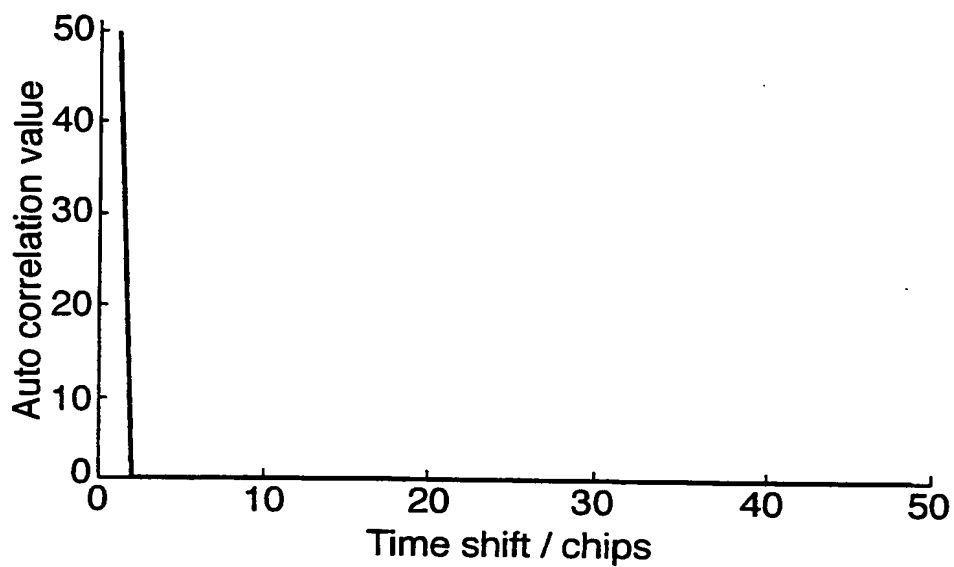
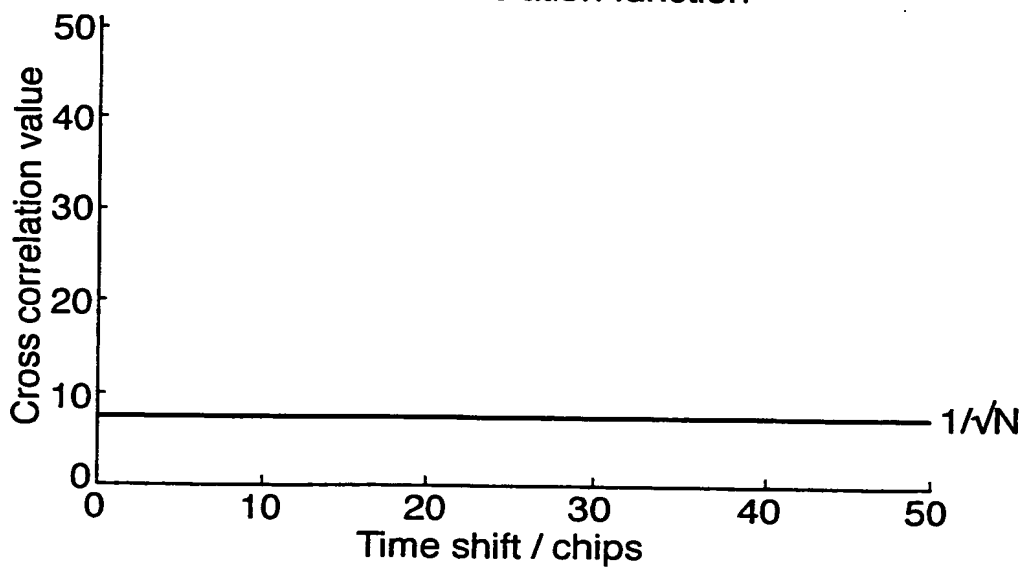


Fig.4b.

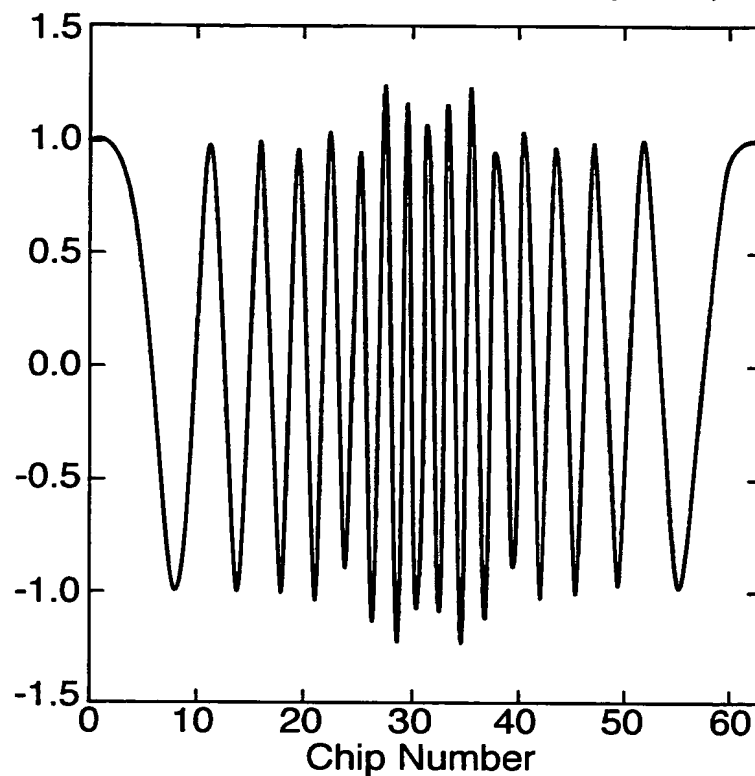
Crosscorrelation function



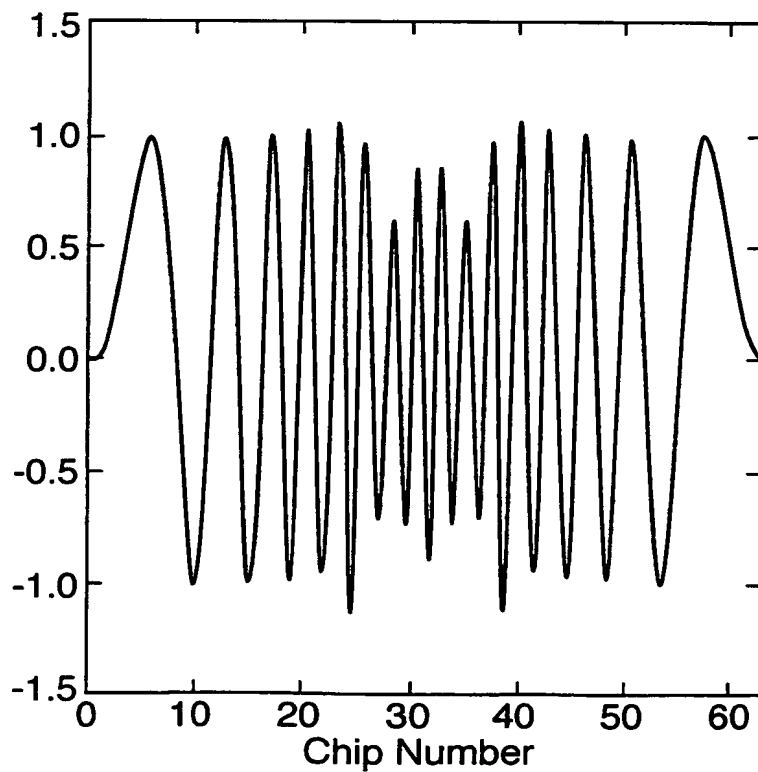
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Fig.5a.

Filtered FZC Sequence (Seq 1 of length 63) - REAL



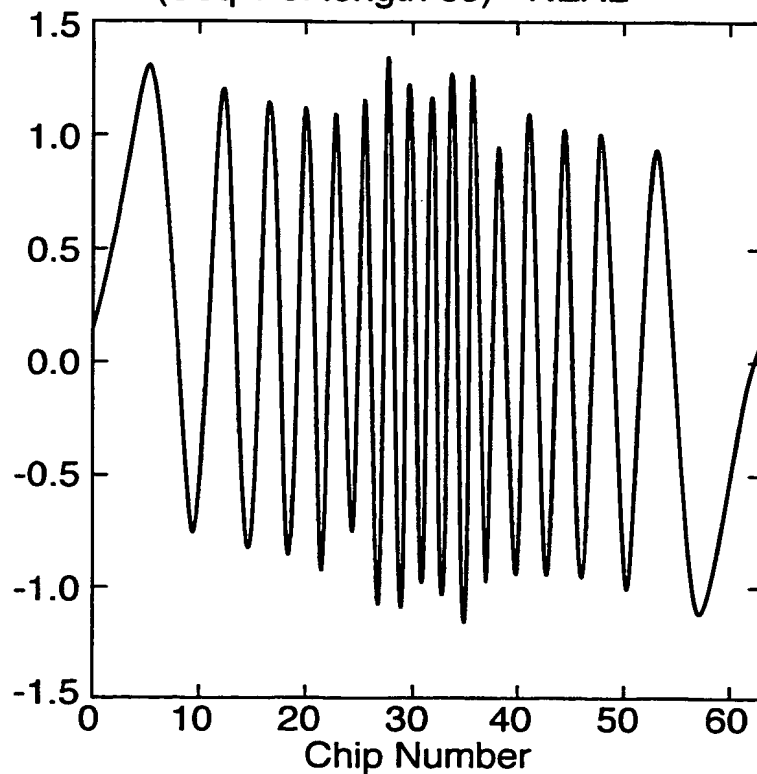
Filtered FZC Sequence (Seq 1 of length 63) - IMAGINARY



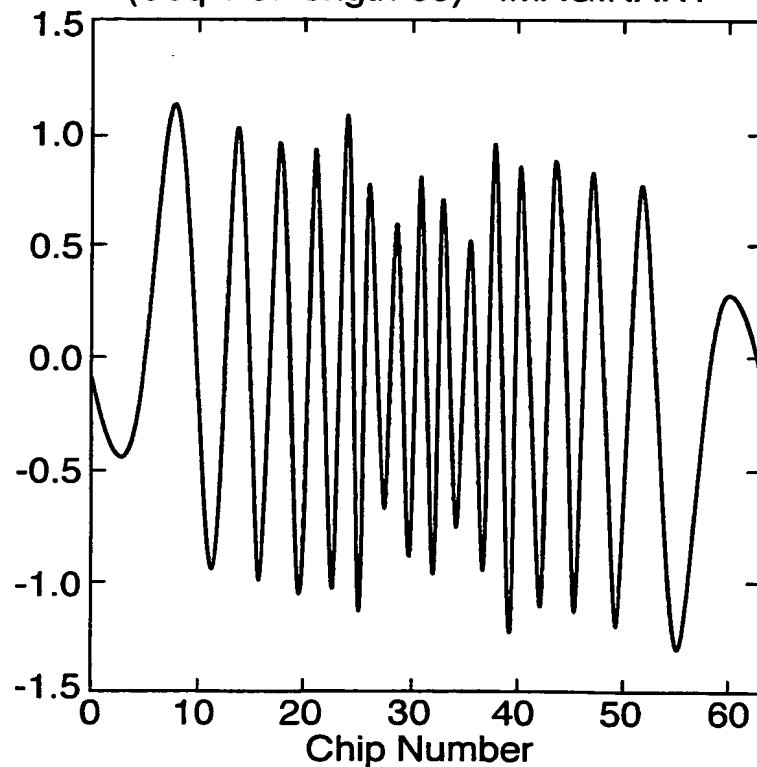
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Fig.5b.

Hilbert T-form of Filtered FZC Sequence
(Seq 1 of length 63) - REAL

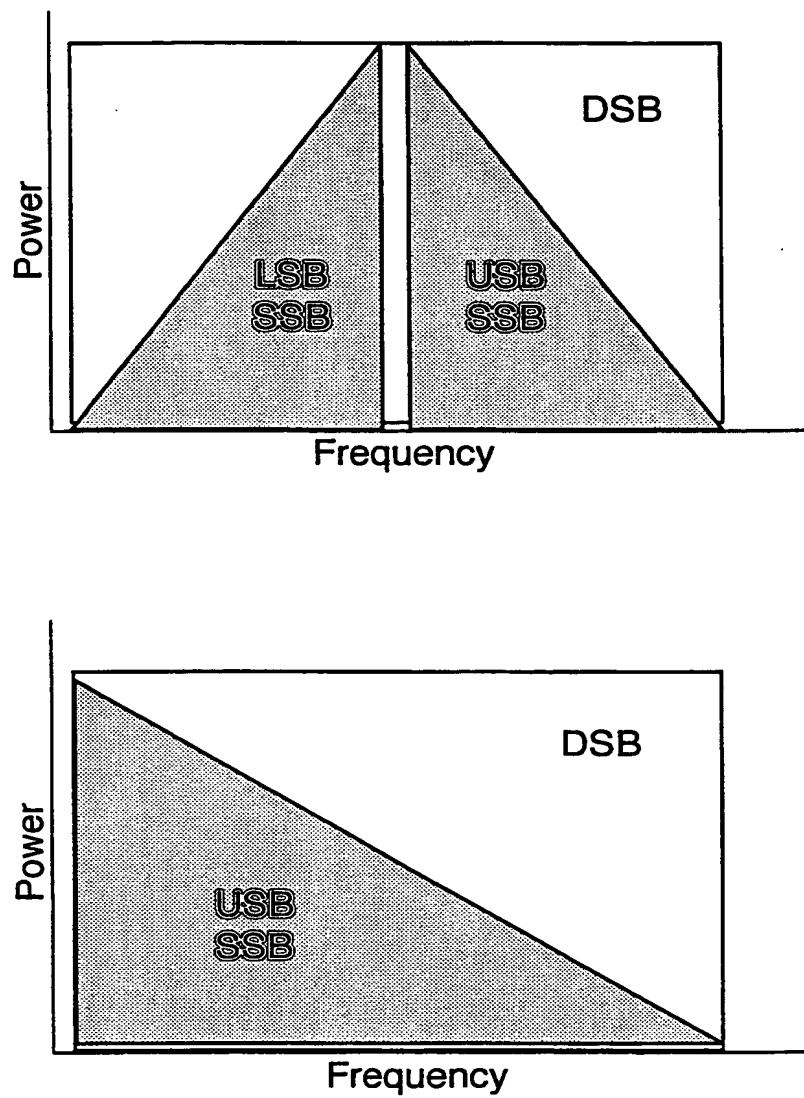


Hilbert T-form of Filtered FZC Sequence
(Seq 1 of length 63) - IMAGINARY



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Fig.6.



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Fig.7.

Performance of DSB, overlay and SSB

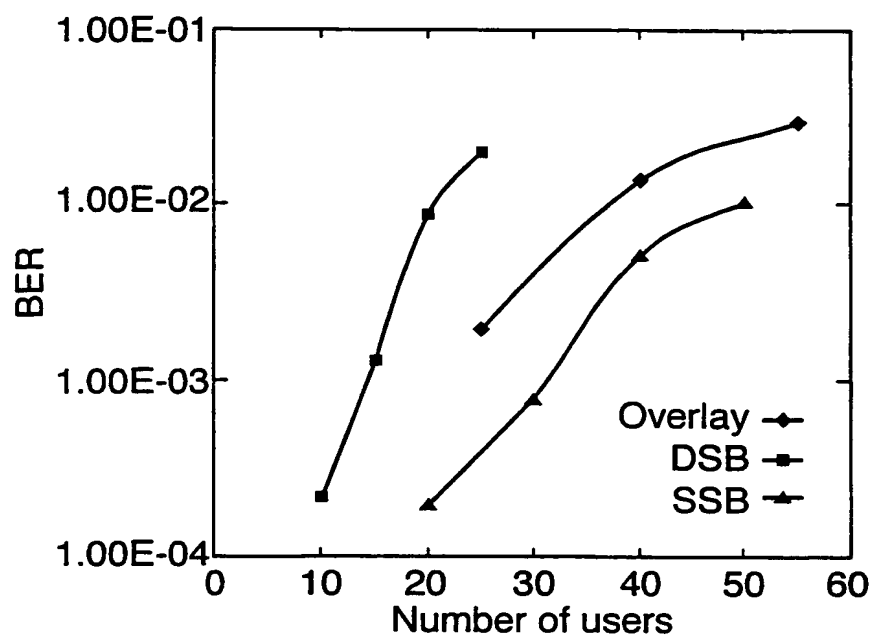
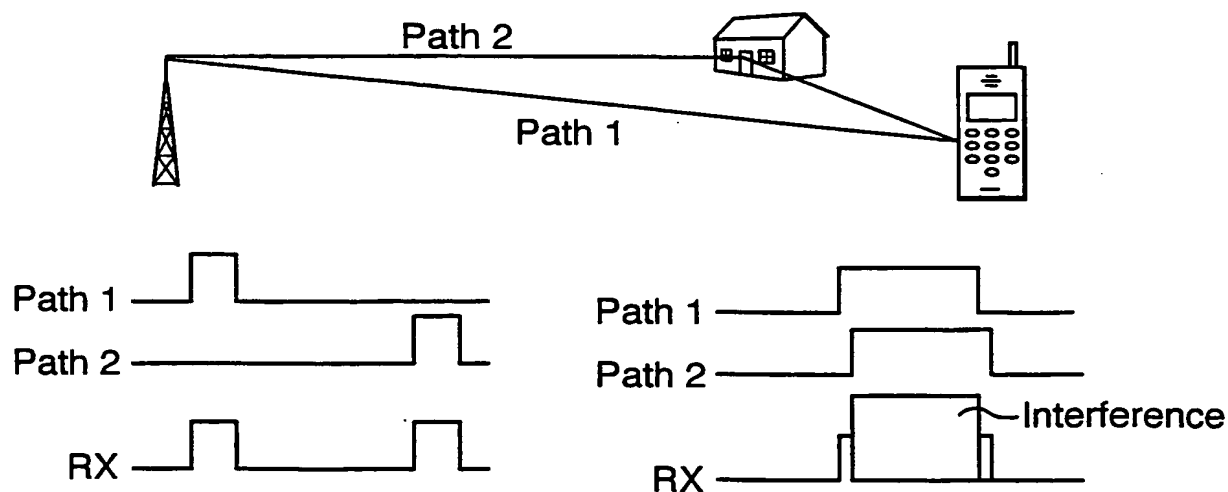


Fig.8.



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Fig.9.

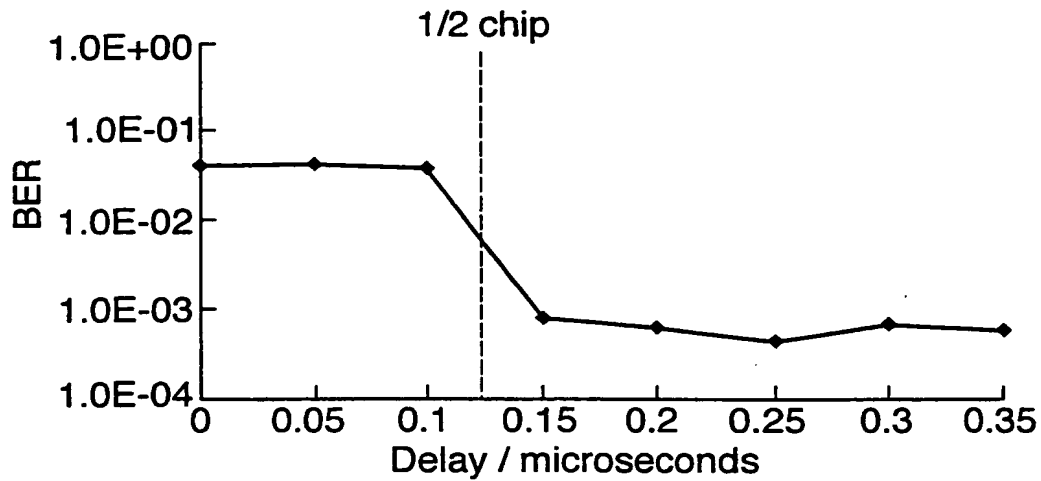
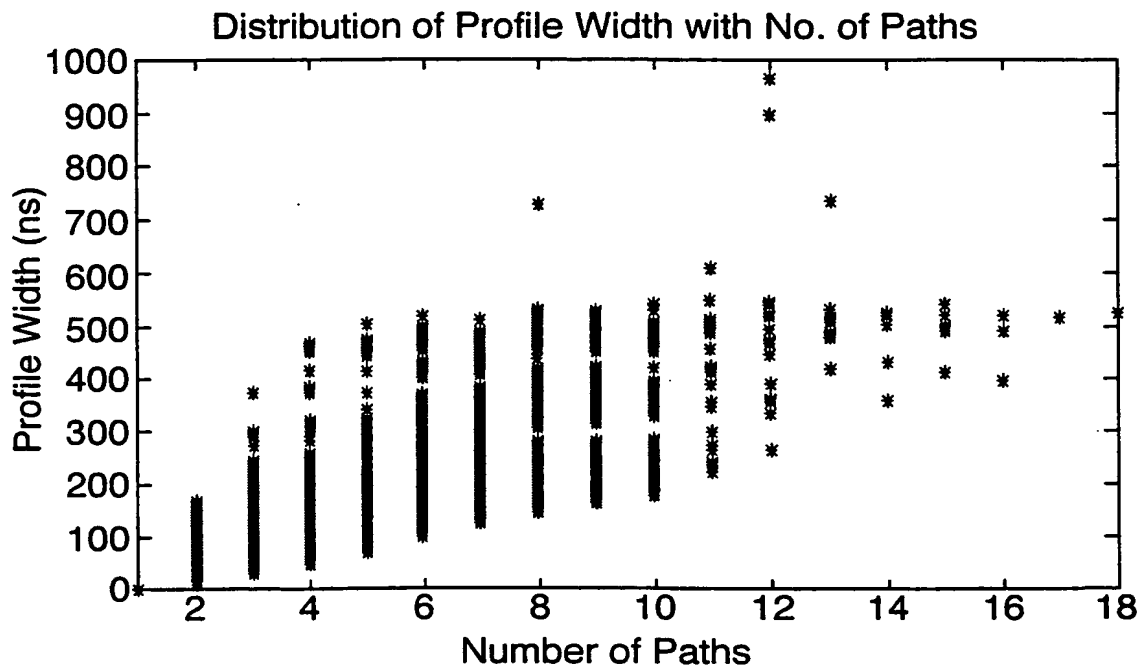
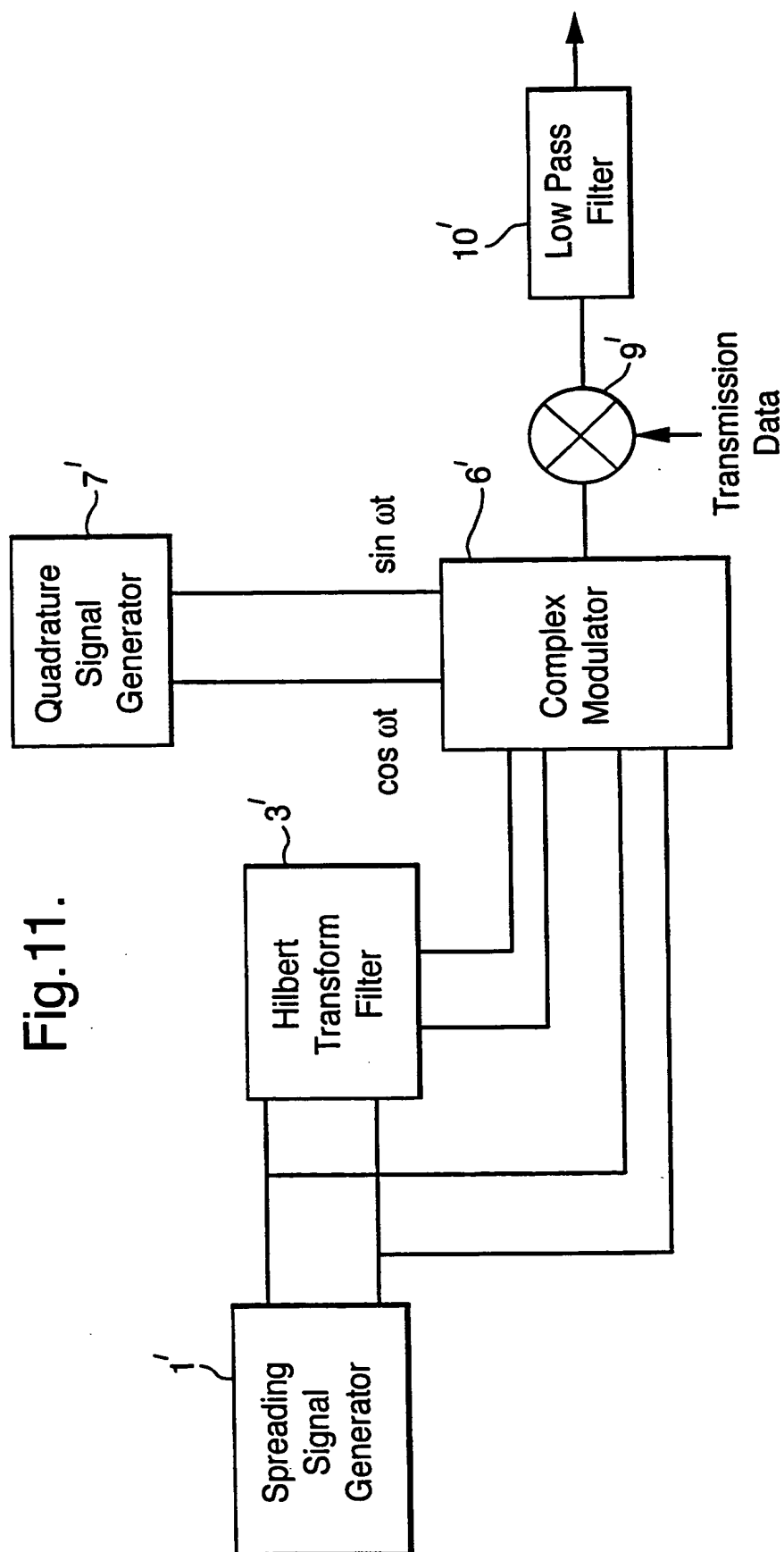


Fig.10.



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INTERNATIONAL SEARCH REPORT

Int. Application No.

PCT/GB 00/02997

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B1/707 H04B1/68

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 675 608 A (JUNG SUNG-HUN ET AL) 7 October 1997 (1997-10-07) column 2, line 4 - line 17; claims 15-20,22,23; figure 3A column 3, line 49 -column 4, line 17 column 5, line 44 -column 6, line 11	1,2,4-8, 10,11,13
A	US 5 422 909 A (STEWART KENNETH A ET AL) 6 June 1995 (1995-06-06) column 3, line 30 - line 50; claims 1,6; figures 5,6 abstract	1,2,7, 11,13
A	US 5 838 719 A (MOORE III TIMOTHY F) 17 November 1998 (1998-11-17) column 2, line 9 - line 23; claims 1-4; figures 3,4A-4D	1,2,7, 11,13
	-/-	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Int. Application No

PCT/GB 00/02997

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>LOTTER M P ET AL: "A class of bandlimited complex spreading sequences with analytic properties"</p> <p>1996 IEEE 4TH INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS PROCEEDINGS. TECHNICAL PROGRAM. (CAT. NO.96TH8210), PROCEEDINGS OF ISSSTA'95 INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS, MAINZ, GERMANY,, pages 662-666 vol.2, XP002127399</p> <p>1996, New York, NY, USA, IEEE, USA</p> <p>ISBN: 0-7803-3567-8</p> <p>cited in the application</p> <p>abstract</p> <p>page 662, left-hand column, line 29 - line 39</p> <p>page 664, right-hand column, line 19 -page 665, left-hand column, line 4</p> <p style="text-align: center;">-----</p>	1-3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 00/02997

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US 5838719	A	17-11-1998	US 5459758 A US 5796959 A	17-10-1995 18-08-1998